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Photocenter variability and AGN components

S. Antón[1,2], A.H. Andrei[3,4,5,6], and F. Taris[5]

[1] Centro de Investigação em Ciências Geo-Espaciais/FCUP, Porto, Portugal
e-mail: sonia.anton@fc.up.pt
[2] SIM, Lisbon, Portugal
[3] Observatório Nacional/MCT, Rio de Janeiro, Brasil
[4] INAF/Osservatorio Astronomico di Torino, Pino Torinese, Italy
[5] SYRTE/Observatoire de Paris, Paris, France
[6] Observatório do Valongo/UFRJ, Rio de Janeiro, Brasil

Abstract. Multi-epoch observations of a set of selected AGNs revealed photocenter jitters at mas level, accompanied by flux variation. Those jitters translate from few parsecs (in most of the objects), to tens of parsec. We discuss possible origins for such photocenter displacements based on the case of 3 objects, two of them having radio jets, the third being a radio-quiet AGN.

Key words. AGN: variability – radio jets – Gaia

1. Introduction

Active Galactic Nuclei (AGN) are among the most luminous objects in the Universe, the output reaching values as high as 10^{47-49}ergs^{-1}. The huge amount of energy comes from extremely small regions, of only few parsecs, as indicated by the flux density being coherently variable with time, on timescales that can be as short as some days. AGN are not temporary phenomena as supernovae or gamma-bursts, but long-lived objects, as e.g. revealed by the presence of kpc-scale structures. It is widely accepted that the central engine of such activity is a supermassive Black Hole (BH, 10^{7-10}M$_{\odot}$), surrounded by a viscous accretion disk. High velocity clouds of gas, moving fast in the BH potential and photoionised by the central continuum radiation field (from the accretion disk), are invoked to explain the broad emission lines detected at optical bands. Some AGNs are prone nonthermal emitters, the origin being jets of plasma interacting with local magnetic fields, revealed by both blobs that move fast, sometimes at superluminal speeds (tens of c), and/or shocks along the jet, as monitoring programs like MOJAVE show.

Among the AGNs, the radio emitters are currently the best targets to build astrometric celestial reference frames. Their coordinates are well established via VLBI techniques, that may reach sub-milliarcsecond accuracy. Objects with core radio morphology, absent proper motions, apparent point-like nature ensure a high degree of accuracy and stability of their coordinates. For this reason they are the defining sources of the quasi-inertial International Celestial Reference Frame (ICRF).

And also for this reason they take part of the objects that will help on the alignment be-

Send offprint requests to: S. Antón

tween radio and the future optical reference frame that Gaia will be able to construct (see Patrick Charlot and Geraldine Bourda contribution).

2. A question of resolution

The improvement of the resolution in the radio band through VLBI techniques produced a major scientific impact in the last decade. An equivalent revolution, in the optical band, is foreseen with the launch of Gaia. The astrometry will be one or two orders of magnitude better than the existent radio one, and the resolution will be on the hundreds of milliarcsec level. Considering that AGNs are the best targets in terms of alignment between ICRF and GCRF (Gaia Celestial Reference Frame, see Francois Mignard contribution), there is an important issue on the stability of their photocenter in the framework of a mission with the level of astrometric accuracy that Gaia will have. At milliarcsecond resolution we are probing regions that are at 10^3-10^6 Schwarzschild radius distance from the BH, for objects with M_{BH}~10^9-$10^7 M_\odot$. It is a region where the accretion disk, BLR and the bases of the jets (when existent) cohabit according to the current AGN paradigm. From this region variable continuum, variable emission line flux, X-ray and γ-ray flares have been detected, showing that it is everything but a steady region. Here we address this question by investigating the impact of flux variation in the photocenter stability of a set of quasars selected by their known high optical variability. Along this paper it is assumed H_o = 71 kms^{-1} Mpc^{-1}, Ω_M = 0.27, Ω_λ = 0.73.

3. Multi-epoch campaign

Andrei et al embarked in a multi-epoch observational program with the ESO 2.2m telescope, the observations taken from April 2007 to December 2009, at roughly each two months. The sample was selected from Teerikorpi (2000) and Maccacaro et al. (1987), and it comprises 20 AGNs. Here we present preliminary results on R images of

Table 1. For each object, the first line quotes R magnitude, redshift, angular scaling in parsecs per milliarcsecond, AGN type: RL meaning radio-loud, BLR meaning broad emission line object, the second line quotes number of comparison stars, the largest astrometric variation and the largest magnitude variation.

0440-003	15.3	0.574	6.532	RL
	33	<0.15	<10	
1510-089	16.9	0.361	5.007	RL
	19	<0.7	<7	
1620+172	16.2	0.112	2.014	BLR
	8	<0.6	<50	

three of them, namely: 0440-003, 1510-089 and 1620+172 (Mrk 877), the first two are radio-loud objects, the third is a radio-quiet. Figure 1 shows the astrometric positions of the photocenter of each of the 3 objects, along time, the gray scale of the data points reflecting the variations in magnitude during the same period. The method for obtaining the astrometric positions and the magnitude variation is partially described in Andrei et al. (2008), the full analysis will be presented elsewhere (Andrei et al., in prep.), here it is summarised as follows. Both the photocenter astrometric position and magnitude estimates are relative quantities. They are computed by comparing the variations of those quantities relative to a set of reference stars that were observed in the same way as the quasars. Here the location and magnitude of the quasar is "frozen" along the time. The averages of (X,Y) and magnitude for the comparison stars (with reference to the quasar as a fixed origin) are obtained and correlated with both the time-line and each other. Schematically:

1. an average frame (usually composed by 3 frames) is obtained per night. The quasar position and magnitude is set to zero;
2. the average frames from the different nights are sequentially adjusted to a super-average frame. The quasar position and magnitude is set to zero;
3. from the super-average frame, common stars are picked up;

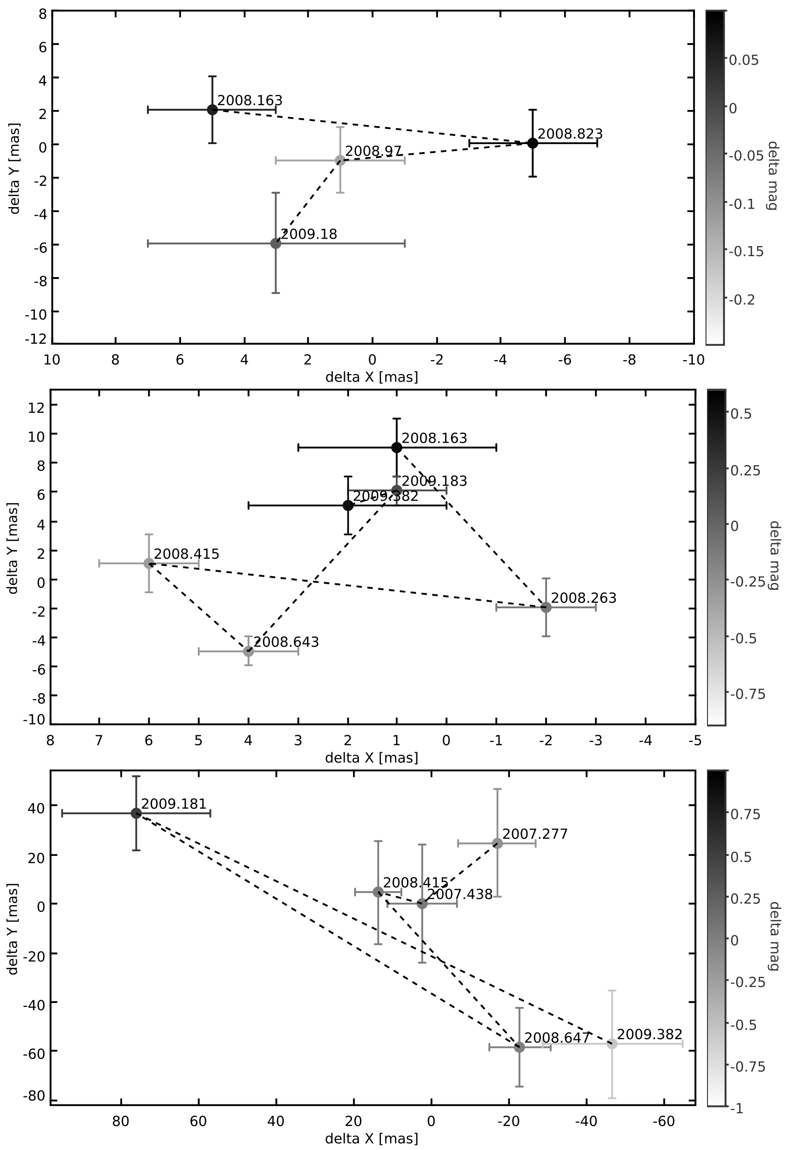


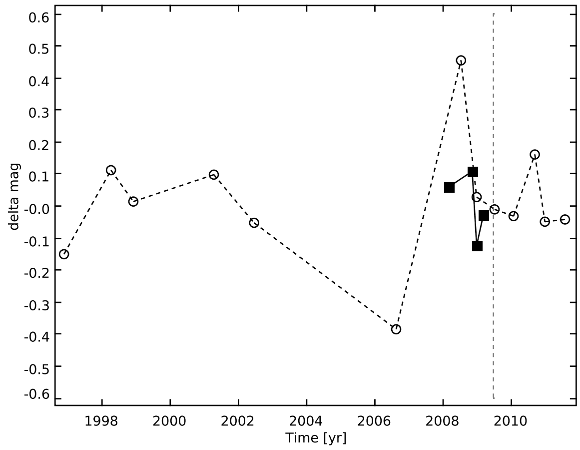
Fig. 1. Variation of the astrometric position of the photocenters, where X is related with RA, Y with DEC, in milliarcseconds, from the previous measurement, of 0440-003 (top), 1510-089 (middle), 1620+172 (bottom), along the observational period. The label of each point refers to the epoch of observation, and the dotted line connects temporally the points. The grey scale refers to the magnitude variation, ie the magnitude variation given in tenths of magnitude from the previous measurement.

4. for each night, the sum of their (X,Y,mag) residuals represent the quasars variation respectively to the super-average frame.

The positional and magnitude errors are typically of 1-4 mas and tenths of magnitude respectively (the uncertainties decreasing as the number of comparison stars rise). Table 1 summarises some information on the objects and on both photocenter and magnitude variation.

4. Origin of the photocenter variability

The main finding is that highly variable quasars show centroid variations of the order of mas range, at the optical regime. This jitter is accompanied by fluctuations in the output energy. Spearman correlation tests on the data indicate a correlation between the X-jitter and the magnitude variation in 0440-003 (Spearman coefficient=-0.88), a correlation between the variation in X-direction and the variation in mag in 1620+172 (Spearman coefficient=0.9) and a correlation between the variation in Y-direction and the variation in mag of 1510-089 (Spearman coefficient=0.77). Converting the mas scale to parsec, in the case of the radio-loud objects the jitter is about few tens of parsec, in the case of the radio quiet the jitter may reach $\sim$ 100 pc. The burning question is what kind of phenomena can explain photocenter wanders that, at least in one case, can reach hundreds of parsec, and is accompanied by variation of flux? Punctual phenomena like Supernovae or a gamma ray bursts cannot explain jitters along 2.5 years. A longer lived phenomena seems more plausible. In the case of "jetted" objects, enhancements in flux due to shocks along the jet, or the appearance of a new blob of plasma are natural candidates. In M87, multi-epoch HST imaging revealed the variation of the output of a jet knot at 0.85 arcsec from the nucleus, that brightened 90 times along a period of 7 years outshining the nucleus of the galaxy (Madrid 2009). In a degraded HST image, with a beam comprising an unresolved core plus the knot, the photocenter would most probably present a jitter along those years. Both 0440-003 and 1510-089 are radio-loud objects, that display radio jets of milliarcsecond extension at 15 GHz, some components showing superluminal motions ($\sim$ 1.15c and $\sim$ 20c, respectively). They have been monitored by the MOJAVE program. The direction of the jitter in both objects roughly coincides with the direction of the radio jet, see map at MOJAVE page. One might argue that the variation of both photocenter and magnitude is the optical counterpart of variation at the radio band. Interesting enough, in the case of 1510-089, see Figure 1, the major enhancements of the magnitude happen in the northeast, a direction that coincides with the appearance of new radio blobs – see MOJAVE radio maps. Figure 2 shows the variation of magnitude at radio band (MOJAVE data) and optical band (our data). Is obvious that the temporal coverage of the optical data is not sufficiently good to make firm conclusions. We note however that there is a hint of correlation between both bands in the case of 1510-089, with the optical emission leading the variation – we displayed the corresponding radio points in gray to guide the discussion. This would be the expected case if the variation was due to flares in the jet. In the case of 0440-003 the situation is not so clear, as there is no clear trend between the two curves. More, Fermi detected a major TeV flare in this object, at the temporal position indicated by the vertical dotted line, but there is no obvious (major) radio counter part seen from MOJAVE data, at least covering the following 1.5 years. 1620+172 is a completely different case in the sense that no radio jets may be invoked to try to understand both the photocenter and magnitude variation. It is a radio-quiet object, with no detection at FIRST at 0.4 mJy level. The photocenter makes excursions of several mas. Popovic et al. (2012) try to simulated the displacements of photocenter due to perturbations in the accretion disk emissivity, but they conclude that the origin of variability must be something else. Interesting enough, when analysing the jitter of the photocenter of 1620+172, we can see that during most of the time the object's photocenter jittered along some tens of parsec, but in one epoch there was a major variation, the photocenter "travailing" almost hundred pc away, and with the largest variation of its magnitude. This may be interpreted as a "Punctual" phenomena. Like a SN or gamma-ray event. Swift detected this source



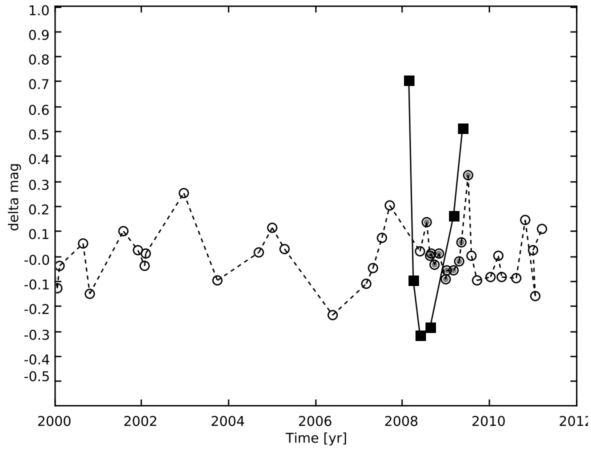


Fig. 2. Variation of the magnitudes at the radio band (empty symbols), the fluxes were obtained from MOJAVE, and the variation of the optical magnitudes (black symbols), along the time, for 0440-003(up) and 1510-089 (bottom). See text for the explanation of the gray symbols in 1510-089, and vertical dotted line in 0440-003.

in September of 2011, temporally too far from our optical observations, nevertheless this indicates the existence of energetic processes occurring therein, of the kind detected in SN events. A follow up of this object is needed.

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